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Kaon Physics at Fermilab Main Injector

Y. Hsiung

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

March 1992

Talk given at the *KEK Workshop on Rare Kaon Decay Physics*, KEK, Tsukuba, Japan, December 10-11, 1991.

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For *high precision* and *high sensitivity* studies of the physics of kaon decays, the important characteristics of the new Main Injector at Fermilab are its *high energy* (relative to other "factories") and its *high intensity*. Experiments of this kind are becoming increasingly important in the study of CP violation and for searches for new interactions. An extracted beam of 120 GeV will produce a source of high energy kaons (10-50 GeV) that will not be surpassed in intensity by any facility now under consideration world-wide[1].

INTRODUCTION

The search for the *origin* of CP violation has been a major effort at Fermilab in the kaon physics over the last decade. The most recent efforts[2] have been concentrated on a search for "direct" CP violation in $K_{L,S} \to 2\pi$ decay (ε'/ε), a test of CPT conservation ($\Delta\phi$), on a search for the mode $K_S \to \pi^+\pi^-\pi^0$ (η_{+-0}), and on a search for $K_L \to \pi^0 e^+ e^-$ which, in the Standard Model model, has a large "direct" CP violating component. These efforts provide means of distinguishing the Superweak hypothesis from the Standard Model. The latest result on ε'/ε from the full analysis[3] of Fermilab experiment E731 ($+0.0006 \pm 0.0007$) does not confirm the CERN NA31 experiment claim[4] of significant evidence for "direct" CP violation ($+0.0023 \pm 0.0007$). The question of Standard Model *versus* Superweak remains open. Experimental efforts aimed at addressing this question will be pursued well into the 90's, first at the Tevatron[5] (KTeV) and then at the Main Injector[1] (KAMI) as described below.

At present, the Fermilab experiments at the Tevatron have superb sensitivity for these modes even in comparison to the dedicated rare kaon decay program at BNL where the proton intensity is significantly higher. The advantage for these and other modes arises primarily from the *higher energy* of the decay products. However, to make substantial progress, much more flux than is available at the Tevatron is required.

PRIOR TO THE MAIN INJECTOR

Let's consider the likely evolution of this field in the years prior to the Main Injector. If we look broadly at the field of "rare" and "CP-violating" kaon decay physics, we note that the best searches for the lepton number violating decays $K_L \rightarrow \mu e$ and $K^+ \rightarrow \pi^+\mu^+e^-$ come from BNL experiments[6] and the sensitivities for these are nearing the 10^{-11} level. These results might be improved[7] by another order of magnitude there. The interesting mode $K^+ \rightarrow \pi^+$ + "nothing" seems to be best done with a stopped charged kaon beam and there BNL-E787 has the best experiment with a limit of 5×10^{-9} on the branching ratio of $K^+ \rightarrow \pi^+\nu\bar{\nu}$. This effort could probably be upgraded[8] to better than 10^{-10} sensitivity at the level of Standard Model prediction; both these upgrades make use of the BNL Booster.

We now consider the CP violating modes. There are continued movement toward higher sensitivities along with the development of needed techniques and byproduct physics at the Fermilab Tevatron. The $K_L \rightarrow \pi^0e^+e^-$ sensitivity is now in the 10^{-9} range as a result of a combination of BNL-E845[9] and FNAL-E731[10] and it will be pushed to nearly the 10^{-11} level, approaching the level expected from Standard Model, in a KTeV experiment E799II. There is also a dedicated experiment[11] at KEK pursuing the $K_L \rightarrow \pi^0e^+e^-$ mode to the sensitivity at 10^{-10} level. The sensitivity to ε'/ε is now at the level of 7×10^{-4}, with all of the E731 data, and is similar for NA31 at CERN; it is proposed to improve the sensitivity to about 1.0×10^{-4} in a KTeV experiment E832. The E773, an experiment to test CPT conservation, which has taken data in 1991, will measure both $\Delta\phi$ and ϕ_{+-} to 0.5°.

For the proper execution of both KTeV experiments E799 and E832 at the Tevatron, the detector and the kaon beam need substantial upgrades. A new large, high-resolution electromagnetic calorimeter (an array of bars of pure CsI crystals) is proposed for the two KTeV experiments. Results[5] on a CsI test array have shown that good energy resolution (<1%) and good position resolution (~1 mm) can be achieved. The pure CsI crystals can be made transparent enough to reduce the non-linearity by more than factor of 10 compared to lead-glass. The longer block (27 radiation lengths) and the reduced non-linearity will also greatly improve the constant term in the resolution. Thus the line-shape becomes more and more Gaussian, greatly facilitating the understanding of the calorimeter response. The radiation hardness test in the hadron beam has also shown that the CsI crystal can be made hard enough to resist high radiation dosage up to 15 kRad without degradation on the light output and uniformity. The studies are still in progress, but it appears that a systematic uncertainty of better than 10^{-4} in the K_S/K_L ratio for the ε'/ε measurement can be obtained;

and a π^0 mass resolution better than 1 MeV for the rare decay search can be achieved. The required upgrades will be important for the subsequent utilization of the much higher intensity kaon beam using the Main Injector. The same CsI calorimeter can be used in the Main Injector kaon experiment.

KAONS AT THE MAIN INJECTOR

When the Main Injector first delivers a high intensity kaon beam in five to six years, what issues should be confronted? The answer will, of course, depend very much of the results in the intervening years. In all likelihood, a new generation of ε'/ε experiment will be needed. Of course, if the results of the previous generation experiment still leave in doubt the issue of a non-zero signal, the case for motivating a new effort is quite clear. Even a first signal in the B system is unlikely by this time so we would still have only the one (laboratory) manifestation of this important phenomenon. However, even if there is an established non-zero result, it will be important to pin down the result with higher precision. Some recent calculations of ε'/ε tend toward lower amounts of direct CP violation, $\varepsilon'/\varepsilon < 0.001$. In the Standard Model, as the value of the top quark mass increases, the expected value[12)] of ε'/ε decreases. When the value of the top mass is known, the range of possible values for ε'/ε will decrease motivating a more definitive test. Such an experiment in the 2π system will likely require over 10^8 $K_L \rightarrow 2\pi^0$ decays with very little background; this would permit a measurement of ε'/ε with a precision of a few times 10^{-5}, at a level where it would be extremely hard for the Standard Model to accommodate a null result.

Closely coupled with the issue of a non-zero ε'/ε is the branching ratio for the $K_L \rightarrow \pi^0 e^+ e^-$ mode which is expected to be of the order of 10^{-11}. A substantial fraction of this decay should be direct CP violation, arising from contributions with virtual top quarks as shown in the diagrams in Fig. 1. The direct branching ratio has been calculated[13)] to be

$$BR\left(K_2 \rightarrow \pi^0 e^+ e^-\right) = 1.0 \times 10^{-5} \left(s_2 s_3 s_\delta\right)^2 G(M_t),$$

where G is a function of the top quark mass of order unity and the original CKM matrix element notation is used. It is easy to show that one can use the constraint on the CKM mixing angles provided by the observed size of the mixing in the neutral B system to express this branching ratio in terms of β, one of the angles of the so-called unitarity triangle, B_B, the bag factor for the B_u meson system, and f_B, the B meson decay constant as well as another function of M_t of order unity:

$$BR\left(K_2 \to \pi^0 e^+ e^-\right) = \frac{5\times 10^{-13}\sin^2\beta}{\left(B_B f_B{}^2 F(M_t)\right)}.$$

Given what we know about the unknowns in the above expression, the value for the "direct" CP violating branching ratio could range from about 10^{-12} to 4×10^{-11} with a central value of about 6×10^{-12}.

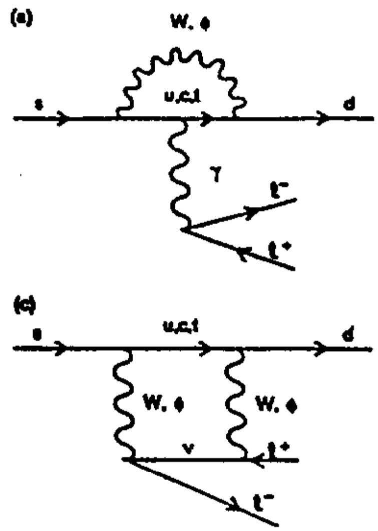

FIGURE 1: Three diagrams giving a short distance contribution to the process $K_L \to \pi l^+ l^-$: (a) the "electromagnetic penguin", (b) the "Z penguin", (c) the "W box". (From C.O.Dib, I. Dunietz, and F. Gilman)

With an extracted beam from the Main Injector, the flux necessary to permit sensitivities to this and other modes in the range of 10^{-10} per hour of running are obtainable. Further, we point out that this will be the best place to perform such experiments of any presently existing or planned facility. The acceptance of the detector to be described for the $\pi^0 e^+ e^-$ mode is about 20% with the requirement that both photons exceed 1 GeV. The decay rate for kaons greater than 10 GeV is about 33×10^6 per spill. However simply accumulating events unfortunately is not enough since there are, in addition to the "direct" CP violating term, three other contributions which need to be untangled. These are an indirect term, coming from the $K_1 \to \pi^0 e^+ e^-$ transition; a CP conserving term, coming from the $K_2 \to \pi^0\gamma\gamma$ intermediate state; and a background coming from the $K_L \to e^+e^-\gamma\gamma$ radiative decay. These have been discussed extensively in the literature.

There is a prediction[14] for the size of the indirect term. Using Chiral Perturbation Theory (and the assumption of octet dominance), the prediction for the branching ratio can be reduced to a two-fold ambiguity: the value should be either 1.5×10^{-12} or 2.4×10^{-11}. This should be directly determined. For the time being, the ambiguity can be broken by a study of the similar $K^+ \to \pi^+e^+e^-$ rate. Experiment E777 at Brookhaven has about 500 of these events with relatively high ee invariant mass. Their spectrum favors[15] a rather stiff distribution for the e^+e^- which suggests the lower value for the corresponding K_1 transition. However, because of the assumptions involved, it will be necessary to determine the K_S rate directly. This could be done at the Tevatron, where the Lorentz factor is favorable, if the rate is high enough. Otherwise, one will need the very high rates at the Main Injector where the K_S amplitude would be determined in an interference experiment.

For the CP conserving transition, there are competing theories[14] which give values between 10^{-14} and 10^{-11} for the two-photon (CP conserving) K_2 transition to π^0ee. There are now two observations[16] of the decay $K_L \to \pi^0\gamma\gamma$ with high values for the $\gamma\gamma$ invariant mass strongly favored in both. This again favors the Chiral Perturbation Theory prediction of the lower branching ratio, although, since the observed rate is in excess of that predicted in lowest order, the conclusion is not yet definite. Further experimental data on $K_L \to \pi^0\gamma\gamma$ will be provided by Fermilab E799.

An important related decay[17] is $K_L \to \pi^0\nu\bar{\nu}$. In the Standard Model this decay is essentially *pure* "direct" CP violating: in principle, the clean observation of just a single unambiguous event would establish the long-sought for effect! Also, the expected branching ratio[18] is about six times greater than for the $\pi^0e^+e^-$ case: a factor of 2 comes because one has both vector and axial vector couplings and a factor of 3 is for three types of neutrinos. Thus the central value is expected to be about 4×10^{-11}. While the background and instrumental problems are challenging, it is worth pointing out that the flux to do the measurement is clearly there at the Main Injector and the relatively higher photon energies are much easier to detect, and to veto.

Another way to see direct CP violation in $\pi^0e^+e^-$ decays is to observe the interference between K_S and K_L near the target. The CP conserving term does not contribute to the interference, and because the K_S branching ratio is about a factor of 300 larger than that of the K_L, the $e^+e^-\gamma\gamma$ background (discussed later) is less of a problem. Thus the result would be much easier to interpret. One way to quote the sensitivity of such an interference experiment is to say that if the branching ratio for the direct CP violating term in the K_L decay were 10^{-12}, we would measure it to 30% precision. The same detector would be used for the interference measurement but with a modified K_S beam.

The ability to study decays close to the production target will also allow measurements of the CP violating parameters η_{+-0} and η_{000}. These, especially the latter, are poorly determined and although the LEAR facility at CERN[19)] will make improvements, it is unlikely that they will see a positive signal let alone be able to be sensitive to departures from the Standard Model predictions. At the Main Injector, one should be able to determine these parameters with much more precision than is presently known, based upon scaling from the experience of E621 and E731. In a similar vein, very precise tests of CPT conservation can be made.

We finally mention the search for lepton flavor violation. Although there are no compelling arguments for the level where such violations should become observable, many classes of theories[20)] for extensions of the Standard Model include such new interactions. The higher the sensitivity, the greater the mass reach; while there is dependence upon coupling constants, an experiment with a sensitivity of 10^{-13} will probe mass scales up to about 350 TeV! We should mention that while it is important to also look for the corresponding decays in the B meson system, the sensitivity to a broad class of new phenomena there is significantly less.

We are thus considering essentially *four* classes of experiments for the kaon facility at the Main Injector. Each would run separately and would utilize and emphasize different elements of the detector; in addition, the configuration of the beam would be optimized for each effort. The four different classes we denote by "High Precision" (ε'/ε); "High Sensitivity" ($K_L \to \mu e$, $\pi^0\mu e$, $\pi^0 ee$, $\pi^0\mu\mu$, etc); "K-short" (K_S decays, including η_{+-0} and η_{000}); and "Hermetic" ($K_L \to \pi^0\nu\bar{\nu}$). A clean and bright beam of neutral kaons and a high rate, high (4-body) acceptance spectrometer are needed. These must combine to yield statistical sensitivities of 10^{-10} per hour, along with corresponding controls of systematic effects. The Main Injector with 120 GeV protons will provide a unique and copious source of neutral kaons of sufficient energy to make the necessary detection (and vetoing) of photons for theses measurements possible. Figure 2 shows the plan view of the KAMI Facility as it will be configured for many K_L experiments.

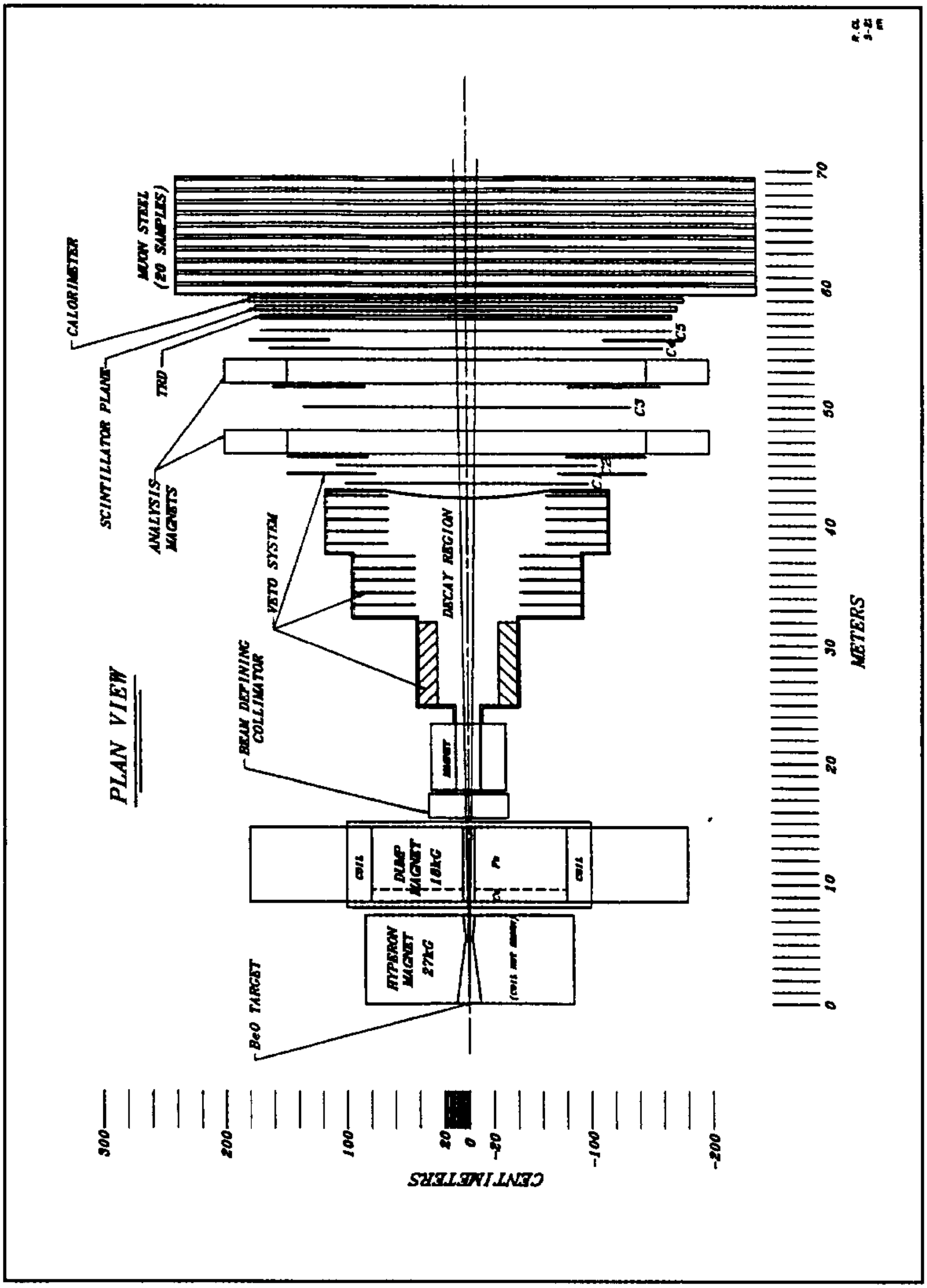

FIGURE 2: Plan view of KAMI Facility from design report showing secondary beam formation, decay space and apparatus. This figure illustrates the "standard" K_L configuration.

Other experiments will require rearangement of the detector elements (e.g. $K_L \rightarrow \pi^0\nu\bar{\nu}$), or rearangement of the secondary beam production elements (e.g. $K_S \rightarrow \pi^0 ee$).

The kaon production spectrum[21)] at a targeting angle of 20 mr is shown in Fig. 3 to compare with the spectrum of the proposed higher flux, lower energy TRIUMF "Kaon Factory". This targeting angle is sufficient to reduce the intense neutron flux by a factor of about 50. The spectra shown assumes no (lead) gamma filter and Beryllium moderator for the purpose of comparison; the loss in kaon flux due to filter and modulator could be recovered for some experiments. The advantage of Main Injector over TRIUMF Kaon Factory is clearly seen, where more kaon flux of higher kaon energy (above 10 GeV) is available for the experiment at Main Injector.

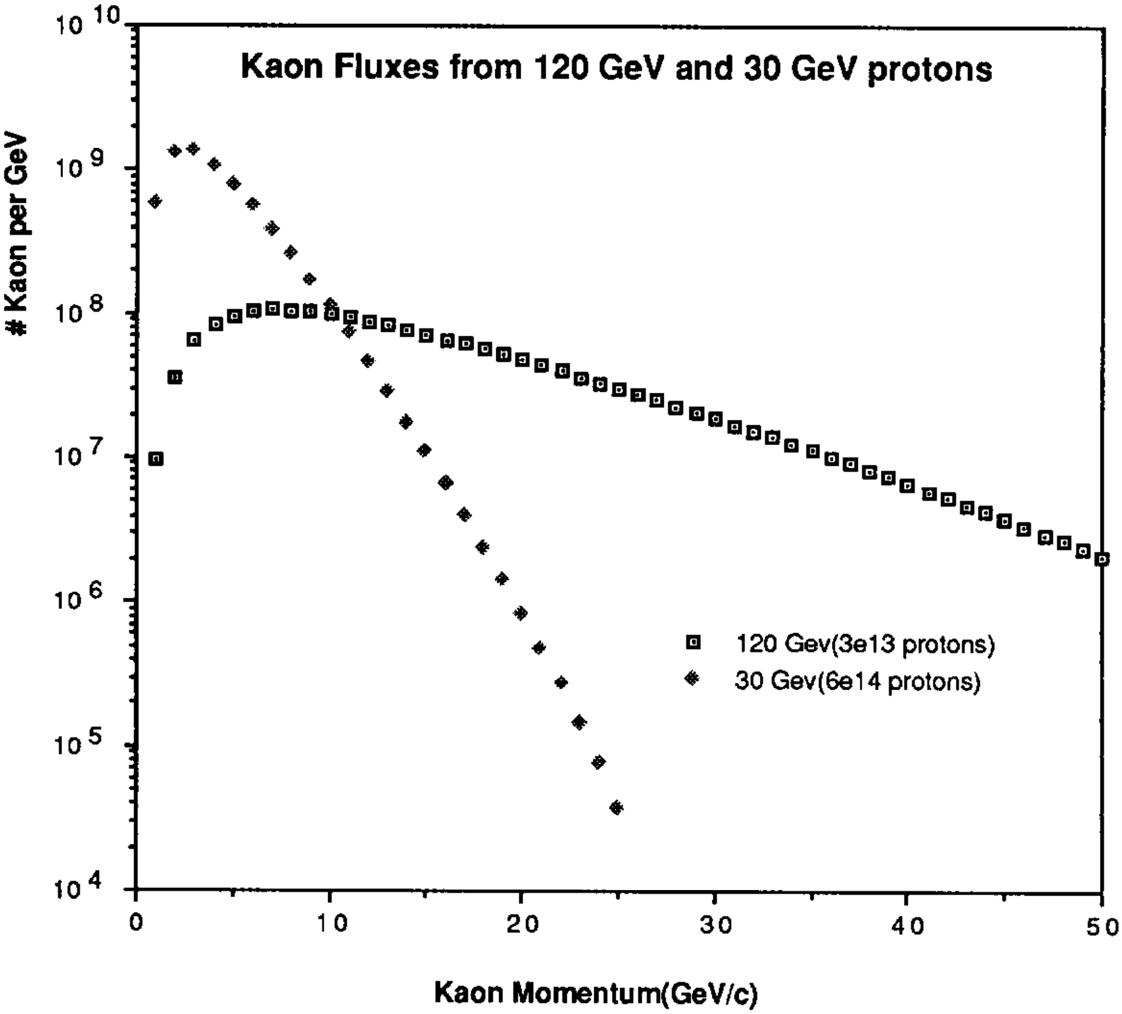

FIGURE 3: Kaon fluxes/sec/GeV for comparison between 120 GeV Main Injector beam (3×10^{13} protons/2.9sec) and 30 GeV TRIUMF Kaon Factory beam (6×10^{14} protons/sec).

We will list some of the advantages of a higher energy machine for such experiments. These have primarily to do with those factors in the experiments which do not scale with energy.

1) With careful attention to reducing the constant term, the resolution of electromagnetic calorimeters will be dominated by the $1/\sqrt{E}$ term so that the higher the energy the better the resolution and resolution is at a premium in such experiments.

2) Background of minimum ionizing particles does not scale with energy: a muon will simulate about 600 MeV energy deposit in an electromagnetic calorimeter so that it is difficult to maintain the same relative threshold level as one decreases the energy. This point is illustrated by the fact that the minimum detectable photon cluster energy was about 1 GeV for both BNL and FNAL Tevatron experiments on ε'/ε and $\pi^0 e^+ e^-$ although the mean kaon energy was more than 10 times greater at FNAL. As a result, the acceptance for the FNAL experiments was significantly greater.

3) Since the growth of hadronic showers is governed by ln(E) rather than E, one needs a fractionally shorter beam dump region at a higher energy facility. As an important consequence, one can be situated relatively closer to the target and thus be more sensitive to K_S decays.

4) The ability to reject events with soft photons outside of the aperture of one's electromagnetic detector is important in reducing background. Again, the dominant problem with a low threshold will be the (non-scaling) minimum ionizing background. This is important for ε'/ε, for $\pi^0 e^+ e^-$ and *especially* for $\pi^0 \nu\bar{\nu}$ where the primary background comes from the $\pi^0\pi^0$ mode.

The successful execution of each of the classes makes demands on the facility and on the detector. The beam on target should be "de-bunched" with only a minimal residual structure (~10%) permitted This is because of the very high rates of kaon decays: at a decay rate of 100 MHz; at the usual 53 MHz of RF structure this would imply near certainty of an overlap of more than one event and, for the high sensitivity experiments where pile-up in the detector is especially troublesome. Debunching of RF structure provides a significant increase in effective duty cycle, enabling essentially uniform spill structure over the 1 second flat top. The incident proton beam should be as free of muon halo as possible and the configuration of the beam definition and beam dump are most important to avoid unacceptable halo (both muon and hadron) around the neutral beam. The kaon decay region contains an anti-coincidence system throughout and must have excellent vacuum. Large aperture high field analysis magnets of suitable uniformity are required for enough precision of the momentum of the kaon decay products and for adequate acceptance. Large aperture tracking detector must also sustain the high singles rate environment due to kaon decays.

We now consider the physics reach of each of the classes of experiments in a one year running period. At this stage, many (but obviously not all) backgrounds[22] have been dealt with and the attainment of the listed sensitivities looks promising.

The "year" that we consider assumes the following. The machine runs with a 1 sec slow spill and a repetition rate of 2.9 sec with an proton intensity of 3×10^{13}. The running efficiency is taken to be 35% which translates into 4×10^6 pulses in a year period. Note that this is very close to the definition of a "Snowmass year", namely 10^7 seconds of operation. Of course one can run for this "year" every year. The beam energy is assumed to be 120 GeV.

We list in Table 1 the rates and sensitivities for each of the measurements and then follow with a discussion of the major features of each. The detector for which the rates and acceptance figures are given were discussed in detail in the KAMI Conceptual Design Report[1].

ε'/ε (High Precision)

For the accurate determination of ε'/ε, one must obtain very high statistics as well as reduced systematic uncertainty. At the Main Injector, the flux is great enough that one can still accumulate the required level of statistics while employing a small target and very small solid angle beams to reduce the level of systematic uncertainty. Very likely a variation of the double beam method of E731 will be employed. To aid in understanding the relative beam acceptances, the proton beam needs to be as stable as possible and we should be able to monitor its position on the target at the 10 μm level. The singles rate in the detectors is modest and is dominated by the interaction rate in the regenerator which is placed in one of the beams. For this to be so, it is necessary that the muon flux at the detector be $\leq 10^{-7}$ per incident proton.

The decay rate shown in Table 1 is only for K_L decays within the fiducial decay volume of about 18 m. The acceptance shown is for the four body $\pi^0\pi^0$ mode and it is large for the higher momentum range indicated; this range is also favorable since the gamma energy resolution improves with energy and, to accurately compare bin-by-bin the decay rates into $2\pi^0$ and $\pi^+\pi^-$, the best possible energy resolution is needed.

Mode	Class	Sensitivity		Beam flux	Target length [cm]	Solid Angle [μstr]	P range [GeV]	Decay rate [MHz]	accep. [%]	singles rate [MHz]	single event sensitivity (per year)
		Today	in 5 yrs.								
ε'/ε	High precision	10^{-3}	10^{-4}	3×10^{13}	8	1	10-50	0.6	35	7.5	$2. \times 10^{-5}$
$K_L \to \pi^0 e^+ e^-$	High rate	10^{-9}	10^{-11}	3×10^{13}	50	12	10-50	33	20	100	3.8×10^{-14}
$K_L \to \mu e$	High rate	10^{-11}	10^{-12}	3×10^{13}	50	12	1-15	33	34	100	2.2×10^{-14}
$K_L \to \pi^0 \mu e$	High rate	–	10^{-10}	3×10^{13}	50	12	10-50	33	20	100	3.8×10^{-14}
$K_L \to \pi^0 \nu \bar{\nu}$	Hermetic	10^{-3}	10^{-8}	3×10^{13}	20	4	2-50	10	20	10	3.0×10^{-12}
$K_S \to \pi^0 e^+ e^-$	K-short	10^{-5}	10^{-8}	1×10^{12}	50	36	10-50	15	30	75	1.0×10^{-12}

TABLE 1: Rates and sensitivities for several K_L decay modes in KAMI.

In the analysis, only 2π decays in a 2 m region downstream of the regenerator for both beams are used; in this fashion systematic uncertainty from any acceptance difference between the two beams becomes small.

The final source of systematic error will be the uncertainty in the residual background. There are effects arising from scattering in the regenerator where a K_S decay can wind up in the vacuum beam (in the neutral mode). With the small beams used and with a fully active regenerator[23] in vacuum (*i.e.* one made entirely of scintillator), this effect is less than 1% and more importantly is identical for charged and neutral decays so that it largely cancels and in any case, it can be very well determined. The background from $3\pi^0$ decays which fake $2\pi^0$ decays is at the 0.4% level in E731; this background is not as easy to simulate and thus it should be lowered significantly. This will be accomplished with a fine grained, high precision electromagnetic calorimeter and in addition an extensive anti-counter system surrounding the decay region to catch missing gammas from this mode. Thus is appears that a determination with nearly 10^{-5} precision could be performed.

$K_L \to \pi^0 e^+ e^-$ (High Rate)

To reach the level of direct CP violation in this mode, it is necessary to run the detector in a much higher rate environment. Many backgrounds are understood[24] for this mode, including a whole variety of accidental effects. The most severe background[25] appears to arise from the $K_L \to e^+ e^- \gamma\gamma$ decay; its branching ratio has recently been determined to be at the level of 5×10^{-7} (depending upon cutoff). These decays tend to have one very low energy gamma and a very low mass *ee* pair. However, after reasonable cuts on these quantities, still a sizable background remains and one has only the π^0 mass as a final constraint. With a high precision CsI calorimeter, this background is about 10^{-11} and one will probably have to live with it at this level. For the indicated configuration and a high sensitivity and high flux experiment at 2×10^{-14} for two years running, a 3 standard deviation measurement of a signal over background can be reached at 3.8×10^{-12} in branching ratio. This corresponds to 80 signal events (presumably direct CP violation) on top of 600 background $e^+e^-\gamma\gamma$ events with a $\pm$ 2 MeV π^0 mass cut, where, according to the Standard Model, a signal should be seen. Figure 4 shows the Main Injector discovering sensitivity in branching ratio at the 40% optimum signal efficiency cut with the presence $e^+e^-\gamma\gamma$ background for a two years running. For this and the other high-rate running conditions, the singles rates are about 100 MHz in the largest chamber but the maximum rate on a single wire (3 mm pitch) is about 600 kHz.

$K_L \to \pi^0\mu^+\mu^-$ can be sought simultaneously with the $\pi^0e^+e^-$ mode. Although the expect direct branching ratio is smaller than the $\pi^0e^+e^-$ mode, it provides another avenue to search for the direct CP violation.

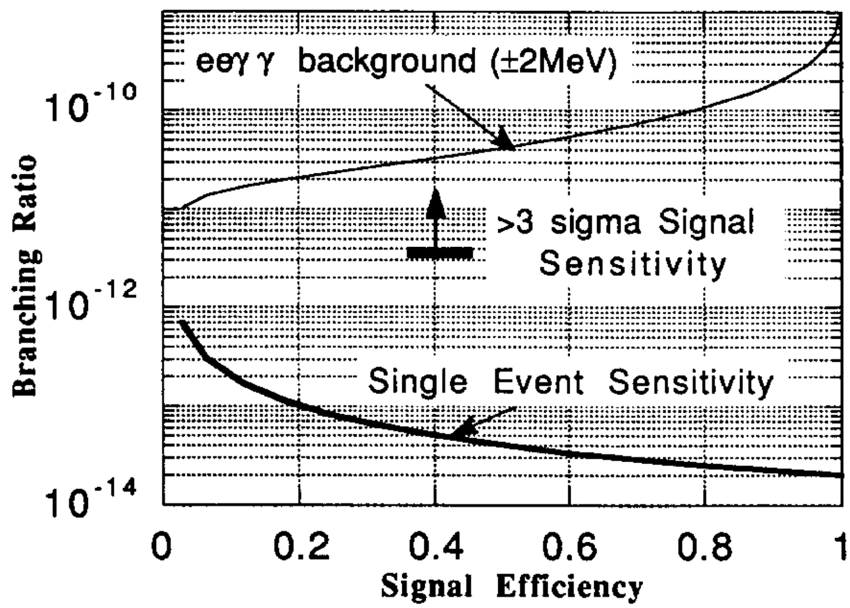

FIGURE.4: Main Injector $K_L \to \pi^0e^+e^-$ discovering sensitivity with the presence $e^+e^-\gamma\gamma$ background for a two year run at the single event sensitivity of 2×10^{-14}. The optimal signal efficiency over the entire Dalitz plot is about 40%.

$K_L \to \mu e$ (High Rate)

The backgrounds to this mode arise from $K_L \to \pi e\nu$ where either the π is mis-identified as a muon, or as an electron with the e mis-identified as a muon. For these backgrounds, it is important to have an extra kinematic handle and this comes from a measurement of the muon range. Hence, the experiment is optimally run in the lower momentum range indicated in Table 1 although the same spectrometer as for the four body decays can be employed. Hence the rates are the same as those discussed above for $K_L \to \pi^0e^+e^-$. Two analyzing magnets (or one with a high enough transverse momentum kick with a chamber in its center) permitting redundant momentum determinations are required for background suppression. At this time, the backgrounds for this mode are only really understood to be less than about 10^{-13} but it is clear that a highly sensitive experiment can be performed.

Currently BNL-E791 has the upper limit $BR(K_L \to \mu e) < 8.4 \times 10^{-11}$ corresponds to 70 TeV mass reach. The new proposal from BNL-E791 collaboration is pursuing to push the limit to 2×10^{-12} (180 TeV mass reach) with the upgrade of Brookhaven AGS booster.

$K_L \to \pi^0 \mu e$ (High Rate)

This mode could also be sought simultaneously with the $K_L \to \pi^0 e^+ e^-$ and $K_L \to \mu e$ searches. The backgrounds are probably less than for the $K_L \to \mu e$ case because the corresponding background process, $K_L \to \pi^0 \pi^\pm e \nu$, has a much smaller branching ratio. Both should be sought in that one does not know *a priori* whether the flavor violating interaction is vector or axial vector, or both. The Main Injector would offer the single event sensitivity to 3.8×10^{-14} for a year running.

$K_L \to \pi^0 \nu \bar{\nu}$ (Hermetic)

For this search, only the instrumented decay volume and the electromagnetic calorimeter are needed. The signature is not terribly stringent: only two electromagnetic clusters in the event, consistent with coming from a single π^0. The dominant, and perhaps only, background comes from the $\pi^0\pi^0$ decay at a branching ratio of 10^{-3}. It is possible to effectively exclude this background by making a P_T cut above the end-point for the $\pi^0\pi^0$ decay. However, because of the finite beam size and the lack of precise information on the transverse vertex position, a Dalitz decay is required to make this cut cleanly. In the end, one would loose about a factor of 10^3 in sensitivity which is probably too great a price to pay. Hence the emphasis is on effectively vetoing the extra gammas. Since the large photon veto system and the calorimeter must form a totally hermetic detector, the calorimeter is re-stacked at the end of the decay space for this experiment.

The decay volume needs a system of anti-counters within the vacuum and the vacuum itself needs to be 10^{-6} Torr in order to eliminate the background from the hadron beam interacting in the residual gas. The problem is difficult because there are many mechanisms by which a photon can be missed and these largely nuclear effects are not well enough known to be certain of the residual inefficiency. This problem has been faced already by the BNL-E787 collaboration at Brookhaven, but in a lower and more difficult energy region and we have benefitted from their experience[26]. Nevertheless, a detailed simulation[27] shows that the single event background level with a hermetic veto system would be better than 10^{-11}. Of course, to be certain, dedicated tests will be in order.

For the exposure indicated in the Table 1, one would have about 80 of these background events and, with the plausible assumption that we would be able to determine this background level independently, after subtraction we would have a three standard deviation sensitivity at about 3×10^{-12}. The rates are modest and the beam is well defined to help exclude background. By using the large P_T Dalitz decays, however, the sensitivity would be about 10^{-10} and could probably be improved by running at higher rates. Considering that at present, the deduced branching ratio is little less than 10^{-3} and that at the Tevatron, one will improve this to perhaps 10^{-8} level, this represents a major advance. We also should point out that with such a hermetic detector there is the potential for the discovery of other unexpected decay modes.

CONCLUSION

With the advent of the Main Injector, there is the possibility of doing a whole new generation of experiments in neutral kaon physics. Although the energy of the Main Injector is not as high as the Tevatron, the average number of protons deliverable per hour is about two orders of magnitude greater! With these beams, it is possible to probe with ever greater precision and sensitivity the fundamental questions of CP violation and rare decays. The greater levels of precision in probing CP violation (ε'/ε, $K_L \rightarrow \pi^0 e^+ e^-$, $K_L \rightarrow \pi^0 \nu\bar{\nu}$, $K_S \rightarrow \pi^0 e^+ e^-$) and of sensitivity in testing lepton flavour conservation ($K_L \rightarrow \mu e$, $K_L \rightarrow \pi^0 \mu e$) achievable in these experiments will provide stringent tests of the Standard Model and important windows on potential new physics.

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